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DEVELOPMENT AND VALIDATION OF A NEW TECHNIQUE FOR MEASURING PROTEIN QUALITY OF FEEDS FOR FEEDLOT CATTLE AND HIGH PRODUCING DAIRY COWS

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Development and Validation of a New Technique for Measuring Protein Quality of Feeds for Feedlot Cattle and High Producing Dairy Cows

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Final Report

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By

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Executive Summary

The overall objective of this project was to determine if cannulated pigs can be used to determine intestinal protein disappearance of rumen undegraded residues from a wide variety of feedstuffs in cattle. A graduate student (Miss Dawn Loveday) was recruited for the project and started her program in the fall of 2000. The results formed the basis of her M.Sc. program.

Research work was conducted in two separate areas. The first study area focused on refining the mobile bag technique in ruminants and attempted to standardize the technique. The results of this area showed that when using this technique, the following parameters should be considered:

1. Drying time after washing should be for 48 h at 55 degrees C.
2. Bag size should be standardized to 2.5 x 4 cm.
3. Washing time after recover from feces needs to be for 10 seconds and repeated 5 times.
4. Surface area to sample size ratio had a minimal effect on results.
5. There is no need in ruminants for a pepsin / HCl pre-incubation in order to mimic abomasual digestion, however, in pigs this practice is commonly used.
6. Bag material had minimal influence on nutrient disappearance. Due to the high nitrogen content of nylon bags, polyester material is preferred.

With this information it was possible to move onto the primary objective of the work which was to determine if cannulated pigs could serve as a model for determining intestinal digestion of rumen undegraded feed residues in ruminants. This work formed the basis for study area 2.

The results of study area 2 show that cannulated pigs can serve as an accurate model for determining intestinal digestion of feed residues in ruminants. Intestinal and total tract DM disappearance in pigs explained 95 to 100% (r^2) of the variation in intestinal and total tract DM disappearance in steers. Residual standard deviations for these regression equations ranged from 1.60 to 5.23%. Bias analysis of these equations

indicated that the pig model underestimated the DM disappearance of steers by 3.5 to 17.1%. Intestinal and total tract CP disappearance in pigs explained 77 to 100% (r^2) of the variation in intestinal and total tract CP disappearance in steers with residual standard deviations ranging from 1.65 to 6.38%. Bias analysis of these equations indicated that the pig model underestimated CP disappearance of the same feeds in steers by 1.0 to 4.0%, the exception being with forages where it was slightly overestimated (0.14 to 0.26%).

The results of this work are a significant step forward in understanding and determining the extent of post-ruminal protein and fibre digestion in ruminant animals. The results indicate that cannulated pigs can be used as an animal model to measure intestinal digestibility of rumen undegradable feed protein when using the mobile nylon bag technique. The mobile nylon bag technique is ideal for testing a large number of feedstuffs, especially when there is only a small amount of sample available. In addition, it is a rapid and easy method for measuring intestinal digestibility of rumen undegradable protein for ruminants. Cannulated pigs can be managed at a lower cost than cannulated cattle, since they eat less, take up less space in the barn, and require less expensive handling systems.

Introduction

The in situ nylon bag technique helps ruminant nutritionists to understand the dynamics of nitrogen in the rumen. It allows us to measure the disappearance of dry matter and protein from feed samples incubated for different time intervals in nylon bags in the rumen of a fistulated steer or cow. Information from this technique allows us to determine how the crude protein content of a feed is used by the animal. Specifically it gives us a soluble protein fraction, the fraction that is potentially degradable by rumen bacteria, the undegradable or bypass protein fraction, the rate at which the protein is degraded by rumen bacteria and the extent to which it is degraded (Ørskov 1992). Knowledge of the extent of rumen degradation and the degree to which a given protein source bypasses the rumen is critical to new methods of formulating rations for beef and dairy cattle (NRC Beef 1996; NRC Dairy 2001). The rumen nylon bag procedure, however, does not provide evidence of availability of feed protein that bypasses the rumen. Intestinal availability of feed protein is critical to accurately predicting and meeting the protein needs of high producing ruminant animals.

A second technique known as the mobile nylon bag technique (MNBT) has been used in both cattle and pigs to determine intestinal availability of crude protein. Furthermore when this technique is used with the in situ rumen nylon bag technique discussed above, protein digestibility over the entire gastrointestinal tract of the animal can be determined (Stern et al. 1997; De Boer et al. 1987). The mobile nylon bag technique is a rapid indicator of the availability of rumen undegradable protein in feedstuffs. It can determine the extent of heat or other damage to protein during processing or storage (De Boer et al. 1987). It can be used to partition rumen and intestinal digestibility of protein and dry matter (Kopencý et al. 1998).

The practical application of these two nylon bag techniques is that they give nutritionists a better understanding of rumen degradable (RDP) and undegradable (RUP) protein and how to classify protein sources for these 2 forms of protein. Using this method, we can determine if we are feeding the correct balance of RUP and RDP to get the most efficient use of dietary nitrogen (Murphy et al. 1986; Murphy and Kennelly 1986).

In swine, the mobile nylon bag technique is most commonly used to determine the apparent protein digestibility of feeds (Sauer et al. 1983). Although the mobile nylon bag technique is most commonly used to estimate protein digestibility, it can also be used to measure the digestibility of other nutrients including dry matter, carbohydrates, and energy. It allows for the rapid determination of nutrient digestibility of complete diets or individual feed ingredients, including feeds of low palatability (Sauer et al. 1983).

Problems with using the mobile nylon bag procedure in cattle include cost of the animals, including initial cost, feed and housing costs and more expensive surgery costs. Pigs in contrast are less expensive and easier to house, feed and care for. Using pigs as a model to measure intestinal protein digestibility in cattle would reduce research costs and improve the ability of ruminant nutritionists to study protein requirements of beef and dairy cattle. Theoretically, it should be possible to use pigs as a model for cattle since the digestive tract of cattle post-ruminally is similar to pigs. Other monogastric species could be used for this experiment, but since the mobile nylon bag technique originated in pigs there already is a reliable procedure to measure intestinal protein digestibility in this species.

Objective

The overall objective of this project was to determine if cannulated pigs can be used to determine intestinal protein disappearance in cattle of a wide variety of feedstuffs. In order to accomplish this task, a graduate program for Miss Dawn Loveday was set up. This research fulfilled in part the requirements for a Master of Science degree for Miss. Loveday who started her program in the fall of 2000.

Study Area 1

Analysis of Methodological Factors Affecting Protein Digestibility Using the Mobile Bag Technique

Introduction

Although, many researchers have used the mobile bag technique (MBT) successfully to determine intestinal availability of RUP, some questions remain. Methodological factors affecting the MBT have been evaluated extensively with pigs; however, little research has examined these same affects in cattle. Every research paper has used slightly different procedures regarding factors such as sample size, pepsin treatment, or bag size that could alter the results from the MBT. This makes comparisons between experiments difficult. If this method is to be more reliable, factors affecting methodology need to be standardized and validated. This study will clarify some of these questions regarding the methodology of this procedure.

Some of the variations between experiments are the following. Most studies revealed that they used polyester bags in cattle with a size of 3.5 x 5.5cm (De Boer et al. 1987), while pig trials used smaller nylon bags that are a size of 2.5 x 4.0cm (Cherian et al. 1989; de Lange et al. 1991; Sauer et al. 1983). No research to date with cattle has studied the effects of bag material or bag size on intestinal nutrient disappearance. Cherian et al. (1989) has evaluated how bag size affects nutrient digestibility in pigs.

A few people have determined how bag size affects retention time and found that larger bags tend be recovered in the feces later than smaller bags (Erasmus et al. 1990; Teixeira et al. 1988; Voigt et al. 1985). There has been research by Voight et al. (1985) and Hvelplund (1985) that indicate the retention time in the digestive tract has minimal effects on protein digestion in the small intestine.

Studies have examined the effects of pre-incubation in a pepsin-HCl solution. Most have concluded that it is not necessary when the MBT includes pre-incubation of feeds in the rumen (Mustafa et al. 2000; Vanhatalo et al. 1995).

Although most research papers stated that the bags were washed, no experiment has been done that compares different washing times on nutrient disappearance. This may explain the large variation between studies from washing the bags in a domestic

washing machine for 50min (Vanhatalo and Ketoja 1995; Van Straalen et al. 1993) or 10min (Erasmus et al. 1990) to rinsing the bags under cold tap water for an unreported length of time (Kopečný et al. 1998; Mustafa et al. 2000).

Like washing techniques, drying times tend to also vary considerably between experiments. Drying times varied from 24h at 60°C (de Boer et al. 1987; Kopečný et al. 1989; Varvikko and Vanhatalo 1990) to 48h at 60°C (Arieli et al. 1999). Sample size to surface area ratio also varies between studies from using 0.5g of rumen undegradable residue in 3.5 x 5.5cm bags (de Boer et al. 1987) to using 0.5g of rumen undegradable residue in 3 x 6cm bags (Van Straalen et al. 1993). In pigs, it is common to use a bag size of 2.5 x 4.0cm with a 0.5g or 1.0g of sample (de Lange et al. 1991; Sauer et al. 1983; Viljoen et al. 1997; Cherian et al. 1988). Therefore, with so much variation in methodology between experiments using the mobile bag technique, standardization is essential.

Objective

The objective of this study was to test a variety of factors that could affect dry matter and protein disappearance using the mobile bag technique in cattle. Seven factors were examined, these include animal variation in the retention time bags are in the animal, washing time, drying time, sample size to surface area ratio, bag size, bag material, and pepsin treatment.

Methodology

Steer Model

Three steers were used for the first three trials, for the other trials, two steers were used. In the summer of 2000, three Hereford steers initially weighing about 636Kg were picked out of a group of steers with flexible rumen fistulas. The three steers were then surgically fitted with a simple-T cannula into the proximal duodenum. They were housed and fed individually in 13m^2 pens with concrete flooring and a rubber mat in the Livestock Research Barn at the University of Saskatchewan. The steers were fed twice daily at 0800 and 1600h with a 50:50 barley silage to barley concentrate diet on a dry matter basis in two equal feedings. The barley concentrate included tallow, canola meal,

rumensin, salt, vitamins and minerals. This diet was fed at maintenance level with free access to water. Lighting was continuous and the temperature of the barn remained between 15°C and 25°C. Animals were cared for according to the guidelines of the Canadian Council for Animal Care (1980).

Trial #1

There were three objectives in this study. The first was to determine if there is a difference between steers in the retention time of bags in the intestinal tract. Second, to determine if the size of bags (2.5 x 4.0cm and 3.5 x 5.5cm) affects retention time. The third objective was to determine if retention time affects dry matter and crude protein degradation in the intestinal tract.

Two types of ruminal undegraded residue were evaluated in this trial, canola meal and barley straw. A total of 36 bags were made with 9 bags allocated to each treatment. Treatment 1 was small nylon bags (2.5 x 4.0cm) with 1.0g of canola meal residue. Treatment 2 was small nylon bags with 0.15g of barley straw residue. Treatment 3 was large nylon bags (3.5 x 5.5cm) with 1.0g of canola meal residue and treatment 4 was large nylon bags with 0.48g of barley straw residue. Bags were divided evenly between the steers so that each steer received 3 large straw filled bags, 3 large canola meal bags, 3 small straw bags, and 3 small canola meal bags into the proximal duodenum.

One intestinal bag was put in the duodenum every hour until all bags had been inserted. A volunteer was scheduled to be in the barn at all times until the bags had been collected. All fecal material was checked immediately for nylon bags. The time and date the bags were put in the duodenum and recovered was recorded. Damaged bags were not used.

Bags were washed to remove contaminants such as fecal material and bacteria adhering to the feed particles. When a bag was found it was washed under a gentle stream of cold tap water for 5s then gently squeezed to remove the water. This procedure was repeated three times. Then the nylon bags were placed flat on a tray, which was stored in the freezer until all bags had been collected. The bags were thawed before being put into the oven at 55°C for 48h to dry prior to chemical analysis.

Trial #2

The first objective was to determine how bag size affects dry matter and protein digestibility of rumen undegradable canola meal and barley straw residue. Two different bag sizes used in this trial were 2.5 x 4.0cm and 3.5 x 5.5cm. The smaller size bag is common in pig trials and the larger size is used in cattle trials using the mobile bag technique. The second objective was to determine if the negative and low intestinal dry matter and crude protein digestibility of rumen undegradable straw and canola meal, respectively determined in Trial #1, were due to a poor washing procedure or due to the bags not being dried long enough.

A total of 72 intestinal bags were made, 36 large nylon bags (3.5 x 5.5cm) and 36 small nylon bags (2.5 x 4.0cm). There were four groups of bags each consisting of 18 bags. These groups were large bags filled with 1g of canola meal rumen undegradable residue, large bags with 0.29g of barley straw rumen undegradable residue, small bags with 0.52g of canola meal rumen residue, and small bags with 0.15g of barley straw rumen residue. The sample amounts in the small bags were chosen so that they had the same sample size to surface area ratio as the larger bags. Each steer will get three nylon bags to be inserted into the duodenum for each feed to be tested.

One nylon intestinal bag was inserted into the small intestine through a cannula once every hour. A volunteer was scheduled to be in the barn at all times until the bags had been collected. All feces after 10h, after the first bag had been inserted were checked immediately for bags. Damaged bags were not used for the trial. Immediately, all bags were placed flat on a tray and stored in the freezer until all the nylon bags had been collected.

Two washing times were chosen, the 5s wash repeated three times from trial #1 and a slightly longer washing time of 10s repeated five times. The bags were divided evenly between treatments. Treatment 1 had 36 nylon bags: 9 of each size of bag containing straw and 9 of each size of bag with canola meal. Bags in treatment 1 were washed for 5s under a gentle stream of cold tap water, and then gently squeezed to remove the water. This procedure was repeated three times. Treatment 2 had the same number of bags as treatment 1. These bags were washed similarly to treatment 1, except they were washed five times for 10s. All bags in both treatments were dried in the oven

at 55°C for 48h then weighed. To test if a longer drying time is necessary they were put back into the oven for another 24h at 55°C when the nylon bags were weighed again.

Trial #3

In order to study the effect of an extended washing period on dry matter and protein disappearance a total of 36 polyester intestinal bags (2.5 x 4.0cm) were used. They were filled with either canola meal or barley straw rumen undegradable residue. Eighteen bags were filled with 0.15g of straw and another 18 bags with 0.52g of canola meal.

There were three treatments, each with 6 polyester bags filled with canola meal and 6 bags filled with straw. Treatment 1 bags were washed for 10s under a gentle stream of cold tap water then squeezed to remove excess water; this process was repeated five times. Treatment 2 bags were washed the same way, except the length of time was 15s. Treatment 3 polyester bags were washed for 20s repeated five times. Polyester bags were used because the material consists of less nitrogen than nylon material, which makes it easier to analyze for Kjeldahl N.

As in the above trials bags were placed into the duodenum once every hour. All fecal material was checked hourly 10h after the first bag had been inserted until all polyester bags were found. The date and time were recorded when the bags entered the duodenum and when they were recovered. Any bags that were broken were discarded.

Once a bag was found it was placed on a tray in the freezer until all bags had been collected. The same person then washed all bags to eliminate human variation in washing. Bags were dried for 48h in an oven at 55°C before being weighed to determine dry matter disappearance.

Trial #4

The first objective of this trial was to determine if two different sample size to surface area ratios affect the digestibility of barley straw and barley silage. The second objective was to quantify the degree of bacterial attachment to feed particles after the bags have been through the digestive tract, washed, and dried.

Rumen undegradable barley straw and silage were tested to see if using larger polyester bags with the same amount of sample as in the small polyester bag would improve the dry matter and crude protein disappearance. Each of the two steers was inserted with 4 bags of each treatment. There were four treatments, large bags (3.5 x 5.5cm) with straw, large bags with barley silage, small bags (2.5 x 4.0cm) with straw, and small bags with silage. All bags had 0.15g of sample. Four blank bags each were also made to correct for the nitrogen in the bags.

Problems with negative intestinal dry matter and crude protein digestibility with forage rumen undegradable residues has lead to interest in quantifying the degree of bacterial attachment to the feed still present in the bags after they have been washed and dried. Four rumen undegradable residues were used: canola meal, heated canola meal, barley straw, and barley silage. Small polyester bags (2.5 x 4.0cm) were used in this trial. Two bags of each rumen undegradable residue were inserted into each steer, a total of 4 bags per treatment. Those bags with canola and soybean meal had 0.52g of sample and those bags with barley straw and silage had 0.15g of sample. Blank bags were made to correct for the nitrogen present in the bag when analyzing for Kjeldahl N.

Bags from both parts of this trial were preincubated in a pepsin-HCl solution before being placed in the small intestine. The procedure was as follows. Intestinal bags were grouped into 12 and placed in a 1000ml beaker containing 500ml of a pepsin solution made up of deionized water, 0.01 N HCl, and 1g of purified activated pepsin powder. The solution had a pH of 2.0. The beaker was then placed in a 37°C water bath for 4h and agitated at a rate of 65 oscillations/min. After the bags were removed from the beaker they were rinsed with deionized water. They were dried for a couple hours at room temperature before being frozen at –5°C in small plastic bags until required.

A bag was placed into the duodenum through the cannula once every hour. Fecal material was searched once every two hours from 0800h until 0200h for polyester bags. The insertion and recovery time of each bag was recorded and any bag that was broken was discarded and another bag was put into the same steer the broken bag came from to replace it. Bags that were found were placed on a tray in the freezer until all bags had been collected. They were thawed first before being washed for 10s repeated five times. Bags were then dried at 55°C for 48h at which time they were weighed and

chemically analyzed. Those bags used to measure the degree of bacterial attachment will be analyzed by electron microscopy.

Trial #5

The objective was to test the effects of pepsin-HCl pre-incubation on intestinal digestion of protein and dry matter. Three types of rumen undegradable residue were used, they were canola meal, soybean meal, and dehydrated alfalfa pellets. Small polyester bags (2.5 x 4.0cm) were used again. These small bags were filled with either 0.52g of canola and soybean meal and 0.15g of dehydrated alfalfa pellets. Eight bags for each feed sample were inserted into the duodenum directly and the other eight were put in following pre-incubation in a pepsin-HCl solution, the bags were divided evenly between the two steers. A few blank bags were also made and followed the same procedure as the other bags in order to correct for the nitrogen in the bags when analyzing for Kjeldahl N. These bags in this trial followed the same pepsin-HCl incubation, collecting, washing, and drying procedure as in trial #4.

Trial #6

The objective is to determine if there is a difference in intestinal digestibility of rumen undegradable residue using two types of cloth material, nylon and polyester. As in the above procedure, three types of rumen undegradable residue were analyzed in both nylon and polyester bags. These samples are canola meal, soybean meal, and dehydrated alfalfa pellets. Small bags (2.5 x 4.0cm) were used to test the effect bag material has on dry matter and crude protein disappearance. This time four bags for each sample and treatment were analyzed, two bags went into each steer. Bags either had 0.52g of canola meal and soybean meal or 0.15g of dehydrated alfalfa pellets. Once again, blank bags were used in this trial. All the bags were incubated in a pepsin-HCl solution before being inserted into the duodenum. The bag insertion, collecting, washing, and drying procedures were the same as in trial #4.

Chemical Analysis

Intestinal undegraded residue from all experiments were chemically analyzed for dry matter and Kjeldahl N. From these analyses intestinal dry matter and protein disappearance was determined.

Statistical Analysis

Results were analyzed as a randomized complete block design with the two steers as the block using the PROC GLM procedure of SAS. Significantly different means were separated at $P<0.05$ using the Student-Newman-Keul's test. This determined if there was a difference between the factors tested in each experiment.

Results and Discussion

The intent of this series of trials was to standardize the mobile nylon bag procedure for use in cattle. This series of trials were necessary in order to standardize the technique and to improve the accuracy of the mobile nylon bag technique in cattle. Summarizing the results which are given in Tables 1.1 to 1.13, it is recommended that the following steps be taken to standardize this procedure for use in both cattle and pigs:

7. Drying time after washing should be for 48 h at 55 degrees C (Table 1.3).
8. Bag size should be standardized to 2.5 x 4 cm (Tables 1.2 - 1.4).
9. Washing time after recover from feces needs to be for 10 seconds and repeated 5 times (Tables 1.4 to 1.6).
10. Surface area to sample size ratio had a minimal effect on results (Table 1.7 & 1.8).
11. There is no need in ruminants for a pepsin / HCl pre-incubation in order to mimic abomasual digestion, however, in pigs this practice is commonly used (Tables 1.9 & 1.10)
12. Bag material had minimal influence on nutrient disappearance. Due to the high nitrogen content of nylon bags, polyester material is preferred (Tables 1.11 & 1.12).

With this information it was then possible to move onto the primary objective of the work, to determine how effective the pig is as a model for intestinal digestion of rumen undegraded residues from a variety of feed sources in ruminants. This work is presented in study area 2.

Table 1.1. Effects of animal and bag size on the retention time (h) in the digestive tract of steers.

	Steer				
	1	2	3	Overall Average	SEM[z]
Large Bag[x]	13.9 ± 3.0	12.9 ± 3.3	13.2 ± 2.7	13.3 ± 2.8	1.22
Small Bag[y]	12.2 ± 1.7	14.4 ± 4.0	11.4 ± 1.0	12.6 ± 2.7	1.10
Overall Average	13.0 ± 2.4	13.6 ± 3.5	12.3 ± 2.2		
SEM[z]	0.98	1.55	0.90		

[x] Large bag size is 3.5 x 5.5cm.
[y] Small bag size is 2.5 x 4.0cm.
[z] Pooled standard error of the mean.

Table 1.2. Effects of washing, drying, and bag size on apparent dry matter disappearance of canola meal rumen undegradable residue in the post-abomasal gastrointestinal tract of steers (DM basis).

	Canola Meal					Contrasts (P-value)		
	5[z]		10[y]					
	Large Bag[x]	Small Bag[w]	Large Bag	Small Bag	SEM[u]	Wash Time	Bag Size	Interaction[v]
48 Hour Drying	33.7	32.2	38.8	35.9	1.19	<0.01	0.07	0.59
72 Hour Drying	33.7	32.2	38.9	36.0	1.16	<0.01	0.07	0.56

[z] Washing the bags for 5 seconds and repeating three times.
[y] Washing the bags for 10 seconds and repeating five times.
[x] Large bag size is 3.5 x 5.5cm.
[w] Small bag size is 2.5 x 4.0cm.
[v] Interaction: Wash time vs. Bag size.
[u] Pooled standard error of the mean.

Table 1.3. Effects of washing, drying, and bag size on apparent dry matter disappearance of barley straw rumen undegradable residue in the post-abomasal gastrointestinal tract of steers (DM basis).

	Barley Straw					Contrasts (P-value)		
	5[z]		10[y]					
	Large Bag[x]	Small Bag[w]	Large Bag	Small Bag	SEM[u]	Wash Time	Bag Size	Interaction[v]
48 Hour Drying	-18.1	-10.4	-5.8	-5.2	0.90	<0.01	<0.01	<0.01
72 Hour Drying	-18.4	-10.7	-5.8	-5.1	0.91	<0.01	<0.01	<0.01

[z] Washing the bags for 5 seconds and repeating three times.
[y] Washing the bags for 10 seconds and repeating five times.
[x] Large bag size is 3.5 x 5.5cm.
[w] Small bag size is 2.5 x 4.0cm.
[v] Interaction: Wash time vs. Bag size
[u] Pooled standard error of the mean.

Table 1.4. Effects of washing and bag size on apparent crude protein disappearance (%) of canola meal and barley straw rumen undegradable residue in the post-abomasal gastrointestinal tract of steers after drying for 72 hours (DM basis).

	Washing Time[t]					Contrasts (P-value)		
	5[u]		10[v]					
	Large Bag[w]	Small Bag[x]	Large Bag	Small Bag	SEM[z]	Wash Time	Bag Size	Interaction[y]
Canola Meal	69.7	64.6	74.6	71.1	1.18	<0.01	<0.01	0.71
Barley Straw	-86.0	-41.2	-25.7	-14.1	7.63	<0.01	<0.01	0.03

[u] Washing the bags for 5 seconds and repeating three times.
[v] Washing the bags for 10 seconds and repeating five times.
[w] Large bag size is 3.5 x 5.5cm.
[x] Small bag size is 2.5 x 4.0cm.
[y] Interaction: Wash time vs. Bag size.
[z] Pooled standard error of the mean.

Table 1.5. Effects of extended washing time on apparent dry matter disappearance of canola meal and barley straw rumen undegradable residue in the post-abomasal gastrointestinal tract of steers (DM basis).

	Wash Time			
	10[w]	15[x]	20[y]	SEM[z]
Canola Meal	40.8	40.4	40.4	0.86
Barley Straw	-0.4	-0.9	-1.3	0.55

[w] Washing the bags for 10 seconds and repeating five times.
[x] Washing the bags for 15 seconds and repeating five times.
[y] Washing the bags for 20 seconds and repeating five times.
[z] Pooled standard error of the mean.

Table 1.6. Effects of extended washing time on apparent intestinal crude protein disappearance (%) of canola meal and barley straw rumen undegradable residue in the post-abomasal gastrointestinal tract of steers (DM Basis).

	Canola Meal	Barley Straw
10 seconds[w]	74.0	13.3
15 seconds[x]	73.1	13.6
20 seconds[y]	74.1	13.8
SEM[z]	0.92	2.55

[w] Washing the bags for 10 seconds and repeating five times.
[x] Washing the bags for 15 seconds and repeating five times.
[y] Washing the bags for 20 seconds and repeating five times.
[z] Pooled standard error of the mean.

Table 1.7. Effects of sample size to surface are ratio on apparent dry matter disappearance (%) of barley straw and barley silage rumen undegradable residue in the post-abomasal gastrointestinal tract of steers (DM basis).

Feed	3.9mg/cm^2 [x]	7.5mg/cm^2 [y]	SEM[z]
Barley Straw	-4.5 ± 4.6	-4.1 ± 1.8	1.26
Barley Silage	-0.6 ± 3.8	2.8 ± 1.7	1.30

[x] Large bag size (3.5 x 5.5cm) with 0.15 g of sample.
[y] Small bag size (2.5 x 4.0cm) with 0.15 g of sample.
[z] Pooled standard error of the mean.

Table 1.8. Effects of sample size to surface area ratio on apparent crude protein disappearance (%) of barley straw and barley silage rumen undegradable residue in the post-abomasal gastrointestinal tract of steers (DM basis).

Feed	3.9mg/cm^2 [x]	7.5mg/cm^2 [y]	SEM[z]
Barley Straw	16.7 ± 13.5	16.7 ± 15.2	5.49
Barley Silage	28.2 ± 14.5	31.0 ± 9.8	4.44

[x] Large bag size is 3.5 x 5.5 cm with 0.15 g of sample.
[y] Small bag size is 2.5 x 4.0 cm with 0.15 g of sample.
[z] Pooled standard error of the mean.

Table 1.9. Effects of untreated versus pepsin-HCl treated intestinal bags on apparent dry matter disappearance (%) of canola meal, soybean meal, and dehydrated alfalfa pellets rumen undegradable residue in the post-abomasal gastrointestinal tract of steers (DM basis).

Feed	Untreated	Pepsin-HCl	SEM[y]
Canola Meal	34.3 ± 2.6	35.3 ± 2.5	0.83
Soybean Meal	79.2 ± 4.3	78.2 ± 7.0	2.09
DA Pellets[x]	36.1 ± 4.7	37.0 ± 3.5	1.35

[x] DA Pellets = dehydrated alfalfa pellets.
[y] Pooled standard error of the mean.

Table 1.10. Effects of untreated versus pepsin-HCl treated intestinal bags on apparent crude protein disappearance (%) of canola meal, soybean meal, and dehydrated alfalfa pellets rumen undegradable residue in the post-abomasal gastrointestinal tract of steers (DM basis).

Feed	Untreated	Pepsin-HCl	SEM[b]
Canola Meal	65.7 ± 3.7	67.1 ± 5.3	1.38
Soybean Meal	90.9 ± 5.0	90.6 ± 5.6	1.78
DA Pellets[a]	80.2 ± 2.9	80.8 ± 3.3	1.02

[a] DA Pellets = dehydrated alfalfa pellets. [b] Pooled standard error of the mean.

Table 1.11. Effects of using polyester versus nylon material to make intestinal bags on apparent dry matter disappearance (%) of canola meal, soybean meal, and dehydrated alfalfa pellets rumen undegradable residue in the post-abomasal gastrointestinal tract of steers (DM basis).

	Bag Material		
Feed	Polyester	Nylon	SEM[y]
Canola Meal	32.2 ± 2.0	36.1 ± 2.5	0.96
Soybean Meal	79.7 ± 4.4	79.4 ± 1.5	1.52
DA Pellets[x]	35.0 ± 1.7	34.3 ± 0.8	0.66

[x] DA Pellets = dehydrated alfalfa pellets.
[y] Pooled standard error of the mean.

Table 1.12. Effects of using polyester versus nylon material to make intestinal bags on apparent crude protein disappearance (%) of canola meal, soybean meal, and dehydrated alfalfa pellets rumen undegradable residue in the post-abomasal gastrointestinal tract of steers (DM basis).

	Bag Material[x]		
Feed	Polyester	Nylon	SEM[z]
Canola Meal	58.6 ± 3.8[a]	64.7 ± 3.7[b]	1.11
Soybean Meal	91.1 ± 2.7	92.6 ± 2.8	1.39
DA Pellets[y]	80.5 ± 0.7	72.7 ± 6.7	2.54

[x] Means in the same row with different letters are different ($p<0.05$).
[y] DA Pellets = dehydrated alfalfa pellets.
[z] Pooled standard error of the mean.

Study Area 2

Use of Cannulated Pigs to Model Intestinal Protein Disappearance in Cattle

Introduction

During the past few years there has been interest within the research community to use other animals to model intestinal protein digestibility for cattle. Research using surgically prepared steers is expensive, especially when they have both a rumen fistula and a duodenal cannula. Appropriates facilities are needed near the handlers so that they can keep a close watch on the animals, in this way they become labor-intensive and their feed and housing costs become higher.

Rats and cecectomized roosters have been used as animal models in an attempt to measure intestinal protein digestibility for ruminants. With the rat model, rumen residue is incorporated into the rat's diet as the sole source of crude protein, then the feces is collected and analyzed for undigested nitrogen. The precision-fed cecectomized rooster assay involves force feeding a fasted adult cockerel with a known quantity of the test feedstuff into the crop and collecting the resulting excreta. At the University of Saskatchewan, pigs have been successfully used to model intestinal protein digestibility for steers (Mustafa et al. 2000). Mustafa et al.'s (2000) regression equations showed that cannulated pigs accounted for 96 and 97% of the variation in steer intestinal and total tract digestibility of unheated and heated canola meal samples. More research is required however to look at the use of the technique in a variety of protein supplements and forage sources.

The use of pigs as a model for cattle to measure intestinal protein disappearance in this study will reduce research costs since they eat less and take up less space in the barn. In addition, pigs are easier to handle and require less expensive handling systems. Theoretically, it is possible to use pigs as a model for cattle because the digestive tract of cattle is similar to pigs after the rumen. Other monogastric species could be used for this experiment, but since the MNBT originated in pigs there already is a reliable procedure to measure intestinal protein digestibility in this species.

Objective

The objectives of this trial were:

1. To use the in situ nylon bag technique to determine the rumen undegradable protein of various protein supplements and forages.
2. To use the mobile nylon bag technique to determine the intestinal and total tract protein digestibility of ruminal undegradable residue of various feed samples in both pigs and cattle fitted with a duodenum cannula to determine if pigs can be used as a model for steers.
3. To use linear regression analysis to determine how well pigs fit a model for determining intestinal protein disappearance in cattle.

Methodology

Animal Models

1. Steers

In the summer of 2000, two Hereford steers initially weighing about 636Kg were picked out of a group of steers with flexible rumen fistulas. The two steers were then surgically fitted with a simple-T cannula into the proximal duodenum. They were housed and fed individually in 13m^2 pens with concrete flooring and a rubber mat in the Livestock Research Barn at the University of Saskatchewan. The steers were fed twice daily at 0800 and 1600h with a 50:50 barley silage to barley concentrate diet on a dry matter basis, with equal amounts of feed at each feeding. The ingredients of the barley concentrate included tallow, canola meal, rumensin, salt, minerals, and vitamins. This diet was fed at maintenance level (1.5% of body weight) with free access to water. Lighting was continuous and the temperature ranged from 15°C to 25°C. The steers were cared for by the guidelines of the Canadian Council for Animal Care (1980).

2. Pigs

In the summer of 2001, six Yorkshire x Lacombe gilts, initially weighing about 50Kg were fitted with a rigid T-cannula into the duodenum. They had two weeks to recover after the surgery before the trial began. The gilts were individually housed in metabolic crates, indoors. During the trial they were given 1.5Kg of standard grower

pellets a day, which is maintenance level (3% of body weight). They were fed twice daily at 0900h and 1600h with ad libitum water. Lighting for the pigs was also continuous and the temperature in the barn remained between 20°C to 25°C. These pigs were also cared for according to the guidelines of the Canadian Council for Animal Care (1980).

Feeds to be Tested

The above animals were used to determine rumen and intestinal disappearance of dry matter and protein from several protein supplements and forages. The following is a list of feeds that were used:

Protein Supplements:

Canola meal – regular vs heated (145°C)

Soybean meal – regular vs heated (145°C)

Wet distiller's grains – regular vs heated (145°C)\

Forages:

Barley straw

Alfalfa hay vs dehydrated alfalfa hay

Barley silage vs heated barley silage (145°C)

Heating of Feed Samples

Prior to rumen incubations, canola meal and soybean meal were heated at 145°C ± 2°C for 1h after the sample reached 145°C. The temperature of the sample was measured using a temperature probe. Following heating they were ground to pass a 2mm screen. The wet distiller's grains and barley silage were dried at 55°C for 48h before being heated at 145°C for 1h after the sample reached 145°C. Wet distiller's grains were ground through a 2mm screen. Barley silage, barley straw, alfalfa hay, and dehydrated alfalfa pellets were ground through a 3mm screen. Barley straw was not heated.

Rumen Incubations

Either 7g of protein supplement or 5g of the forage samples were weighed into large nylon bags, measuring approximately 9 x 21cm with a pore size of 40μm. Sample size to bag surface area was between 10 – 20mg/cm^2. Samples of each feedstuff were placed into a polyester mesh bag (15"x 18") and tied with nylon string. One weighted bottle was placed inside the mesh bag and another attached to the rope to make sure the mesh bag would stay in the ventral sac. Rumen undegradable protein was determined by incubating feed samples in the rumen for 12h. All feed samples were inserted into the rumen at 0800h and retrieved at 2000h, for a consistent rumen environment each time. Following removal from the rumen, 10 bags were washed in 1000ml of cold tap water six times, then dried at 55°C for 48h. Ruminal residues were pooled and ground in a coffee grinder. These rumen residues of each feedstuff were used for the intestinal incubations for both the steers and pigs to determine the intestinal disappearance of protein that bypassed the rumen.

Intestinal Incubations for Steers

Small polyester bags (2.5 x 4.0cm; 48μm) were made and either 0.52g of protein supplement was placed into the bags or 0.15g of forages and heat sealed. Intestinal bags were grouped into 12 and placed in a 1000ml beaker containing 500ml of a pepsin solution made up of deionized water, 0.01 N HCl, and 1g of purified activated pepsin powder. The solution had a pH of 2.0. The beaker was then placed in a 37°C water bath for 4h and agitated at a rate of 65 oscillations/min. After the bags were removed from the beaker they were rinsed with deionized water. They were dried at room temperature for a couple of hours before being frozen at -5°C in small plastic bags until required.

Four polyester bags of each ruminal undigested feed sample were inserted through the cannula into the proximal duodenum of each steer at a rate of 1 bag per hour. Also, four empty bags were inserted into the duodenum per steer. These bags were used as blanks to correct for any protein contamination in or on the bag, such as microbes (Moshtaghi Nia and Ingalls 1992). Polyester bags recovered in the feces were washed for 10s under a gentle stream of cold tap water 5 times, and then dried at 55°C

for 48h. Any bag not recovered within 72h or that was broken was not used for this trial. Instead another bag with the same feed sample was put into the same steer to replace it.

Intestinal Incubations for Pigs

As with the intestinal incubation procedure for the steers, 0.52g of protein supplements or 0.15g of forages was weighed into the small polyester bags. These polyester bags were put into a pepsin-HCl solution prepared the same way as above before being incubated in the duodenum. Like the steers, each feed type had a total of 8 bags inserted into the pigs. However, since there were six animals instead of two, the bags were randomly assigned to each pig. This means that each pig was inserted with at least one bag of each feed type, a couple of the pigs had two bags with the same feedstuff. Two polyester bags were placed into the duodenal cannula while the pigs was eating, 15min later another two bags were put into the duodenum. Intestinal bags were put into the pigs during the morning and afternoon feedings. Bags that were either broken or not recovered within 72h were not used for the trial and another bag was used to replace it. Repeated bags were put into the same pig that the broken or unrecovered bag came from.

Chemical Analysis

All feed samples and ruminal undegraded residues were analyzed for Kjeldahl N, moisture, acid detergent insoluble crude protein, acid detergent fiber, and neutral detergent fiber. Intestinal undegraded residue was analyzed for moisture and Kjeldahl N. From the chemical analysis, dry matter and protein disappearance from the rumen, intestine, and total tract was determined.

Statistical Analysis

The statistical analysis will be the same as Mustafa et al. (2000). Data from the pigs and steers was analyzed as a randomized complete block design with the animal as the block using General Linear Model procedure of the Statistical Analysis System (SAS). Significantly different means will be separated at $P<0.05$. PROC REG procedure of SAS will be used for a linear regression of pig intestinal and total tract CP and DM disappearance on steer intestinal and total tract CP and DM disappearance.

Results and Discussion

In this trial, heated samples were included to vary the rumen undegradable protein content and subsequent intestinal digestibility of the subjected feed samples. Heating alters the chemical structure of the protein to decrease its rumen degradability, increase or maintain intestinal digestibility, and not change total tract degradability (Moshtaghi Nia and Ingalls 1992; McKinnon et al. 1995). Ideally, heating should reduce soluble N, increase N associated with the NDF, and minimize the increase in N associated with the ADF fraction (McKinnon et al. 1995). The effects of heating at 145°C for 1 h on chemical composition of protein supplements and forages are presented in Tables 2.1 and 2.2. It was not possible to statistically analyze the influence of heat on the chemical composition of the various feedstuffs because each treatment was applied to a single batch of sample derived from a common source. However, in most cases heating changed the chemical composition of the feed samples. For all feedstuffs, the CP and ADF content remained relatively unchanged. Changes in NDF content were inconsistent across feeds (Tables 2.1 and 2.2). The ADICP fraction should remain the same with heating; if ADICP content is higher it is an indicator of heat damaged indigestible protein. Such heat damage not only reduces rumen degradability but intestinal digestibility as well. Out of all the feedstuffs that were heated, only soybean meal was heated to the point where the NDF content was increased but not the ADICP fraction. Rumen, intestinal and total tract disappearance of heated and unheated feed samples are given in Tables 2.3 to 2.6. Heating reduced ruminal DM and CP disappearance of all samples with the exception of the DM disappearance of dehydrated

alfalfa pellets. This effect was expected and has been observed in a number of studies (Mustafa et al. 2001). In contrast, intestinal DM and CP disappearance was either increased by heating (canola meal DM and CP; alfalfa hay DM and CP) or was similar to that of unheated samples (soybean meal DM and CP; distillers' grains DM and CP; barley silage DM and CP). As a consequence of these differences total tract DM and CP disappearance was reduced for heated canola meal, heat distillers' grains, and heated barley silage relative to the unheated feeds. In contrast, the total tract DM disappearance of dehydrated alfalfa pellets was increased. Single degree of freedom contrasts of steer to pig intestinal DM and CP disappearance. The results of these contrasts indicate that there was a difference in intestinal DM and CP disappearance ($P < 0.05$) between cattle and pigs for canola meal and heated canola meal. In addition, the intestinal DM disappearance of heated barley silage was statistically different ($P < 0.001$) between pigs and cattle as well.

Regression analysis was used to determine how well pigs serve as a model for determining intestinal nutrient disappearance in cattle. Non-linear regression (polynomial and exponential curves) as well as simple linear regression were carried out to determine the relationship between intestinal and total tract DM and CP disappearance of pigs to that of steers. However, even though non-linear regression equations were significant, it was concluded that linear regression best represented the relationship between pigs and cattle because non-linear regressions did not improve the adjusted coefficient of determination by more than 5% (Baker priv. comm.). Tables 2.7 and 2.8 give the regression analysis for intestinal and total tract DM and CP disappearance of rumen undegraded protein and forages sources.

The regression equations were separated into protein supplements, forages, and protein sources and forages combined. The feeds were separated into protein supplements and forages to determine if pigs better predicted the intestinal and total tract nutrient disappearance of either the protein supplements or the forages.

Regression equations relating intestinal and total tract DM and CP disappearance in pigs to that of steers are given in Tables 2.7 and 2.8. Figures 2.1 to 2.4 illustrate these relationships for all feeds tested. Intestinal and total tract DM disappearance in pigs explained 95 to 100% (r^2) ($P < 0.05$) of the variation in intestinal

and total tract DM disappearance in steers. Residual standard deviations for these regression equations ranged from 1.60 to 5.23% (Table 2.7). When forced through the zero intercept it was found that pigs underestimated the DM disappearance of steers by 3.5 to 17.1%. Intestinal and total tract CP disappearance in pigs explained 77 to 100% (r^2) ($P < 0.05$) of the variation in intestinal and total tract CP disappearance in steers. Residual standard deviations for these regression equations ranged from 1.65 to 6.38% (Table 2.8). When the regression equation was forced through the zero intercept it was found that pigs underestimated the CP disappearance of steers by 1.0 to 4.0%, except pigs overestimated the CP disappearance of forages by 0.14 to 0.26%.

The high r^2 values and the low standard errors of prediction for both intestinal and total tract disappearance indicate that duodenally cannulated pigs can accurately predict intestinal and total tract DM and CP digestibility of rumen undegraded residue for a variety of feeds. Overall, cannulated pigs under predicted intestinal DM and CP disappearance of RUDR of beef cattle and the model better predicted the DM and CP digestibility of forages than protein supplements.

These results indicate that the pig model is an accurate model to predict intestinal protein digestibility of rumen undegraded feed residues in cattle. While there have only been two studies with the pig model to-date, both the present results and that of Mustafa et al. (2000) show strong correlations between the two species for the variety of feedstuffs tested.

Conclusions

The results of this study imply that cannulated pigs can be used as an animal model to measure intestinal digestibility of rumen undegradable feed protein when using the mobile nylon bag technique. The mobile nylon bag technique is ideal for testing a large number of feedstuffs, especially when there is only a small amount of sample available. In addition, it is a rapid and easy method for measuring intestinal digestibility of rumen undegradable protein for ruminants. Cannulated pigs can be managed at a lower cost than cannulated cattle, since they eat less, take up less space in the barn, and require less expensive handling systems.

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Table 2.1. Chemical composition of various protein supplements used for the trial (DM basis)

Feed	Parameter[z]			
	CP (%)	ADF (%)	NDF (%)	ADICP (% CP)
Canola Meal	42.1	17.8	25.2	6.2
Heated Canola Meal[y]	41.9	18.9	37.5	18.9
Soybean Meal	49.7	5.5	12.0	1.2
Heated Soybean Meal[y]	48.7	5.7	32.7	1.4
Distillers' Grains	21.3	25.3	63.0	6.3
Heated Distillers' Grains[y]	21.0	24.8	59.4	17.0

[y] Heated to 145°C and then maintained at this temperature for 1 h.

[z] CP = crude protein; ADF = acid detergent fiber; NDF = neutral detergent fiber; ADICP = acid detergent insoluble crude protein.

Table 2.2. Chemical composition of various forages used in the trial (DM basis)

Feed	Parameter[z]			
	CP (%)	ADF (%)	NDF (%)	ADICP (% CP)
Alfalfa Hay	18.3	27.6	30.4	6.5
Dehydrated Alfalfa Pellets[x]	19.6	26.3	35.1	10.6
Barley Straw	5.5	54.4	68.4	10.7
Barley Silage	12.6	25.7	40.0	3.4
Heated Barley Silage[y]	11.6	24.9	40.3	12.9

[x] Commercial heat treatment (Tisdale).

[y] Heated to 145°C and then maintained at this temperature for 1 h.

[z] CP = crude protein; ADF = acid detergent fiber; NDF = neutral detergent fiber; ADICP = acid detergent insoluble crude protein.

Table 2.3. Dry matter disappearance (%) of various protein sources in cattle and pigs (DM basis)

	Rumen	Intestine[x]			Total tract			Contrasts[y]
Feed	Cattle	Cattle	Pigs	SEM	Cattle	Pigs	SEM	Cattle vs pigs
Canola meal	64.3a	24.3c	35.2c	2.66	73.0c	76.9b	0.95	<0.05
Heated canola meal	36.9d	38.4b	49.7b	2.22	61.1d	68.3c	1.40	<0.01
Soybean meal	62.0b	70.8a	73.9a	1.87	88.9a	90.1a	0.71	0.26
Heated soybean meal	43.6c	72.5a	77.5a	1.93	84.5b	87.3a	1.09	0.09
Distillers' grains	33.6e	20.8c	20.2d	2.08	47.4e	47.0d	1.38	0.86
Heated distillers' grains	27.8f	22.9c	26.0d	1.69	44.3f	46.5d	1.22	0.21
SEM[z]	0.61	1.87	2.16		0.97	1.24		

a-f Means in each column with different letters are different ($P < 0.05$).

[x] Calculated as the percentage of rumen undegradable protein that went into the intestine.

[y] Comparison of intestinal and total tract DM disappearance of feeds in pigs vs. steers.

[z] Pooled standard error of the mean.

Table 2.4. Crude protein disappearance (%) of various protein supplements in cattle and pigs (DM basis)

	Rumen	Intestine[x]			Total tract			Contrasts[y]
Feed	Cattle	Cattle	Pigs	SEM	Cattle	Pigs	SEM	Cattle vs. pigs
Canola meal	68.7a	51.2d	64.5b	2.32	84.7b	88.9a	0.73	<0.01
Heated canola meal	23.9d	62.8c	70.9b	2.55	71.7d	77.8c	1.94	<0.05
Soybean meal	47.0b	84.6a	86.7a	1.79	91.8a	92.9a	0.95	0.41
Heated soybean meal	18.1e	86.2a	86.6a	1.72	88.7ab	89.0a	1.41	0.86
Distillers' grains	41.3c	73.8b	71.1b	1.84	84.7b	83.0b	1.08	0.30
Heated distillers' grains	23.3d	70.4b	68.9b	1.81	77.3c	76.1c	1.39	0.56
SEM[z]	0.70	2.15	1.83		1.42	1.20	1.20	

a-e Means in each column with different letters are different ($P < 0.05$).

[x] Calculated as the percentage of rumen undegradable protein that went into the intestine.

[y] Comparison of intestinal and total tract CP disappearance of feeds in pigs vs. steers.

[z] Pooled standard error of the mean.

Table 2.5. Dry matter disappearance (%) of various forages in cattle and pigs (DM basis)

	Rumen	Intestine[x]			Total tract			Contrasts[y]
Feed	Cattle	Cattle	Pigs	SEM	Cattle	Pigs	SEM	Cattle vs. pigs
Alfalfa hay	56.6b	12.4b	15.8b	2.56	62.0b	63.4b	1.11	0.37
Dehydrated alfalfa pellets	58.0a	24.0a	27.8a	3.20	68.1a	69.7a	1.35	0.41
Barley straw	18.7e	-11.0d	-11.7d	1.57	9.7e	9.2e	1.27	0.78
Barley silage	49.9c	-3.6c	-0.1c	2.85	48.1c	49.8c	1.43	0.40
Heated barley silage	41.8d	-1.5c	5.3c	1.05	40.9d	44.9d	0.61	<0.001
SEM[z]	0.37	1.81	2.66		0.97	1.32		

a-e Means in each column with different letters are different ($P < 0.05$).

[x] Calculated as the percentage of rumen undegradable dry matter that went into the intestine.

[y] Comparison of intestinal and total tract DM disappearance of feeds in pigs vs. steers.

[z] Pooled standard error of the mean.

Table 2.6. Crude protein disappearance (%) of various forages in cattle and pigs (DM basis)

	Rumen	Intestine[x]			Total tract			Contrasts[y]
Feed	Cattle	Cattle	Pigs	SEM	Cattle	Pigs	SEM	Cattle vs. pigs
Alfalfa hay	75.7b	44.6b	45.7b	3.54	86.6a	86.8a	0.86	0.82
Dehydrated alfalfa pellets	58.8d	68.2a	66.6a	3.67	86.9a	86.3a	1.51	0.76
Barley straw	38.8e	-48.5d	-49.1d	7.27	9.1c	8.8d	4.45	0.96
Barley Silage	79.5a	9.8c	0.1c	7.33	81.5a	79.5b	1.50	0.37
Heated barley silage	63.6c	-2.7c	2.8c	2.35	62.7b	64.6c	0.86	0.13
SEM[z]	0.28	5.41	4.58		2.73	1.83		

a-e Means in each column with different letters are different ($P < 0.05$).

[x] Calculated as the percentage of rumen undegradable dry matter that went into the intestine.

[y] Comparison of intestinal and total tract CP disappearance of feeds in pigs vs. steers.

[z] Pooled standard error of the mean.

Table 2.7. Regression analysis for intestinal and total tract disappearance of rumen undegraded DM for protein and forage sources

		Non-zero Intercept					Zero Intercept		
	$r^{2\,a}$	Slope		Intercept			Slope		
Item		Value	SE[b]	Value	SE[c]	RSD[d]	Value	SE[b]	RSD[d]
Protein Supplements									
Intestine	0.95	0.97	0.10	-4.16[e]	5.01	5.23	0.90[f]	0.04	5.07
Total Tract	0.98	0.97	0.07	-0.81[e]	4.69	2.81	0.96[f]	0.01	2.52
Forages									
Intestine	0.96	0.92	0.09	-2.78[e]	1.37	2.69	0.83[f]	0.10	3.58
Total Tract	1.00	0.97	0.03	-0.11[e]	1.76	1.60	0.97[f]	0.01	1.39
Protein and Forage Sources									
Intestine	0.98	0.95	0.04	-3.14[e]	1.70	3.85	0.90[f]	0.03	4.29
Total Tract	0.99	0.96	0.03	-0.14[e]	1.82	2.10	0.96[f]	0.01	1.99

[a] Adjusted coefficient of determination.

[b] Standard error of the slope.

[c] Standard error of the intercept.

[d] Residual standard deviation.

[e] Intercept is not different from zero ($P > 0.05$).

[f] Slope is different from one ($P < 0.05$).

Table 2.8. Regression analysis for intestinal and total tract disappearance of rumen undegraded CP for protein and forage sources

		Non-zero Intercept					Zero Intercept		
	r^2 [a]	Slope		Intercept			Slope		
Item		Value	SE[b]	Value	SE[c]	RSD[d]	Value	SE[b]	RSD[d]
Protein Supplements									
Intestine	0.77	1.26	0.30	-22.81[e]	22.52	6.36	0.96[f]	0.04	6.38
Total Tract	0.79	1.00	0.23	-1.74[e]	19.33	3.43	0.98[f]	0.02	3.07
Forages									
Intestine	0.98	0.99	0.07	1.13[e]	3.00	6.38	1.00[f]	0.06	5.65
Total Tract	1.00	1.00	0.03	-0.11[e]	1.80	1.65	1.00[f]	0.01	1.43
Protein and Forage Sources									
Intestine	0.98	0.96	0.04	0.33[e]	2.81	6.17	0.97[f]	0.03	5.86
Total Tract	0.99	0.99	0.04	0.21[e]	2.79	2.63	0.99[f]	0.01	2.49

[a] Adjusted coefficient of determination.

[b] Standard error of the slope.

[c] Standard error of the intercept.

[d] Residual standard deviation.

[e] Intercept is not different from zero ($P > 0.05$).

[f] Slope is different from one ($P < 0.05$).

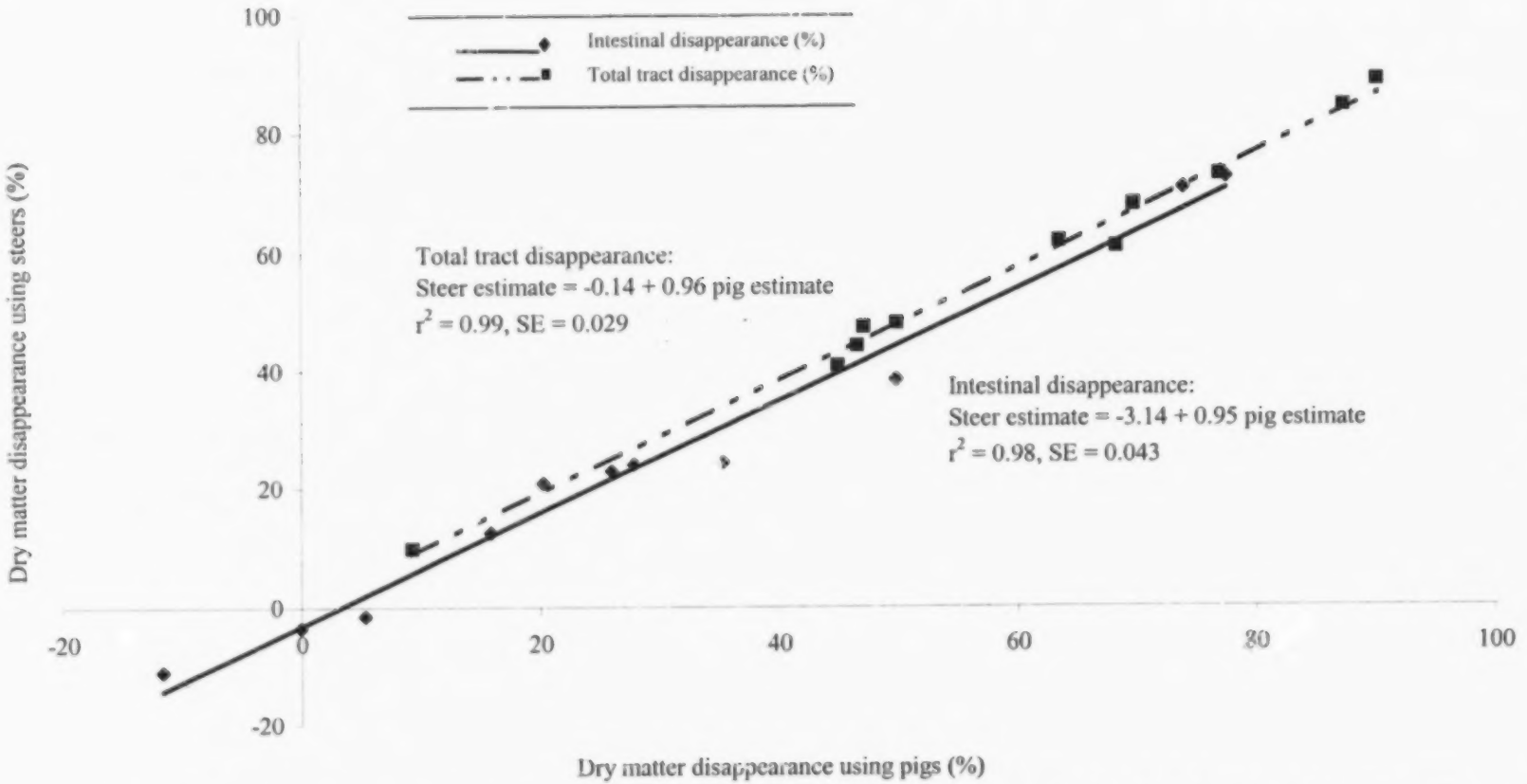

Figure 2.1. Relationship (non-zero intercept) between pigs and steers for measuring intestinal and total tract disappearance of rumen undegraded dry matter of various protein supplements and forages. Each point represents the mean of 16 bags of feed sample.

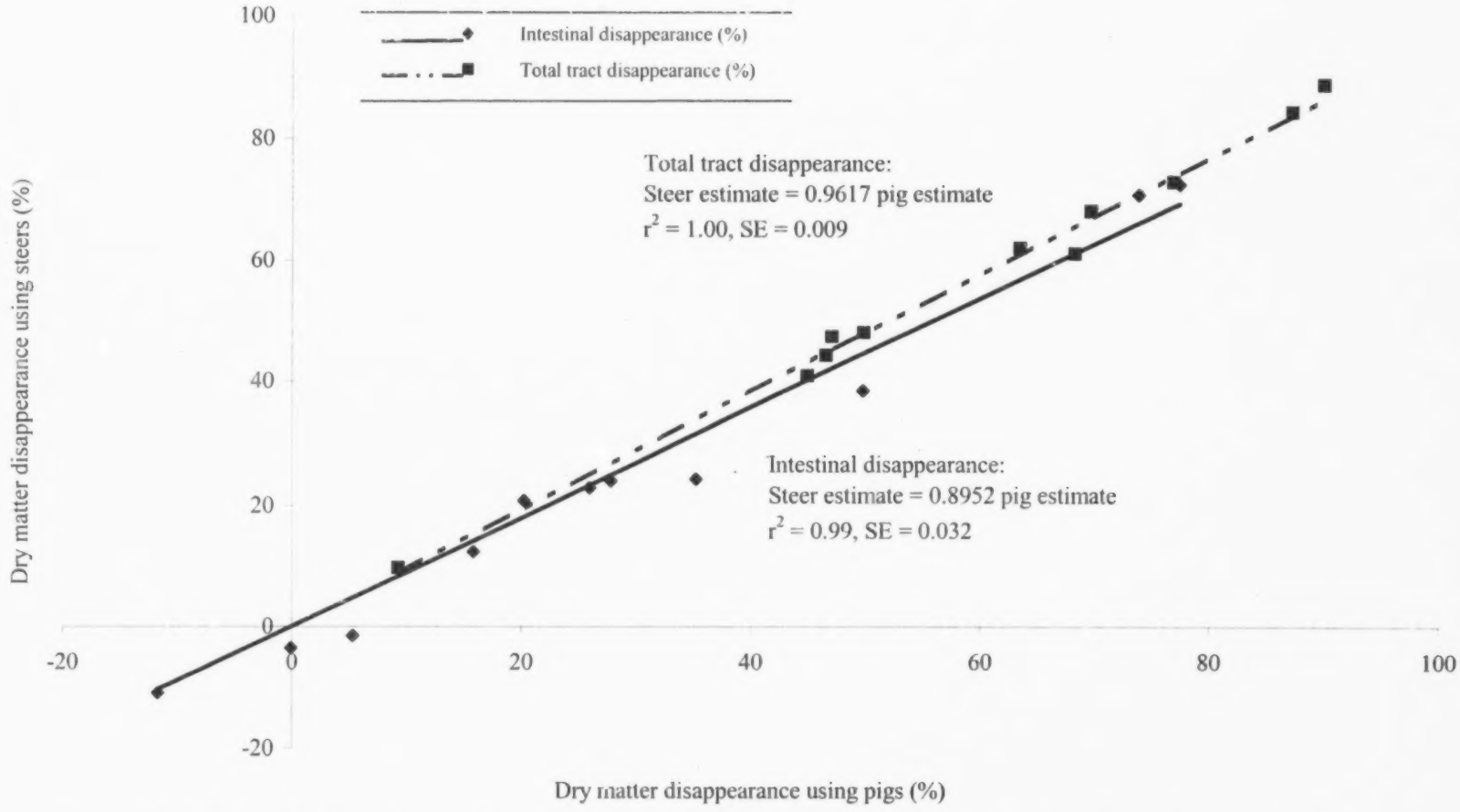

Figure 2.2. Relationship (zero-intercept) between pigs and steers for measuring intestinal and total tract disappearance of rumen undegraded dry matter of various protein supplements and forages. Each point represents the mean of 16 bags of feed sample.

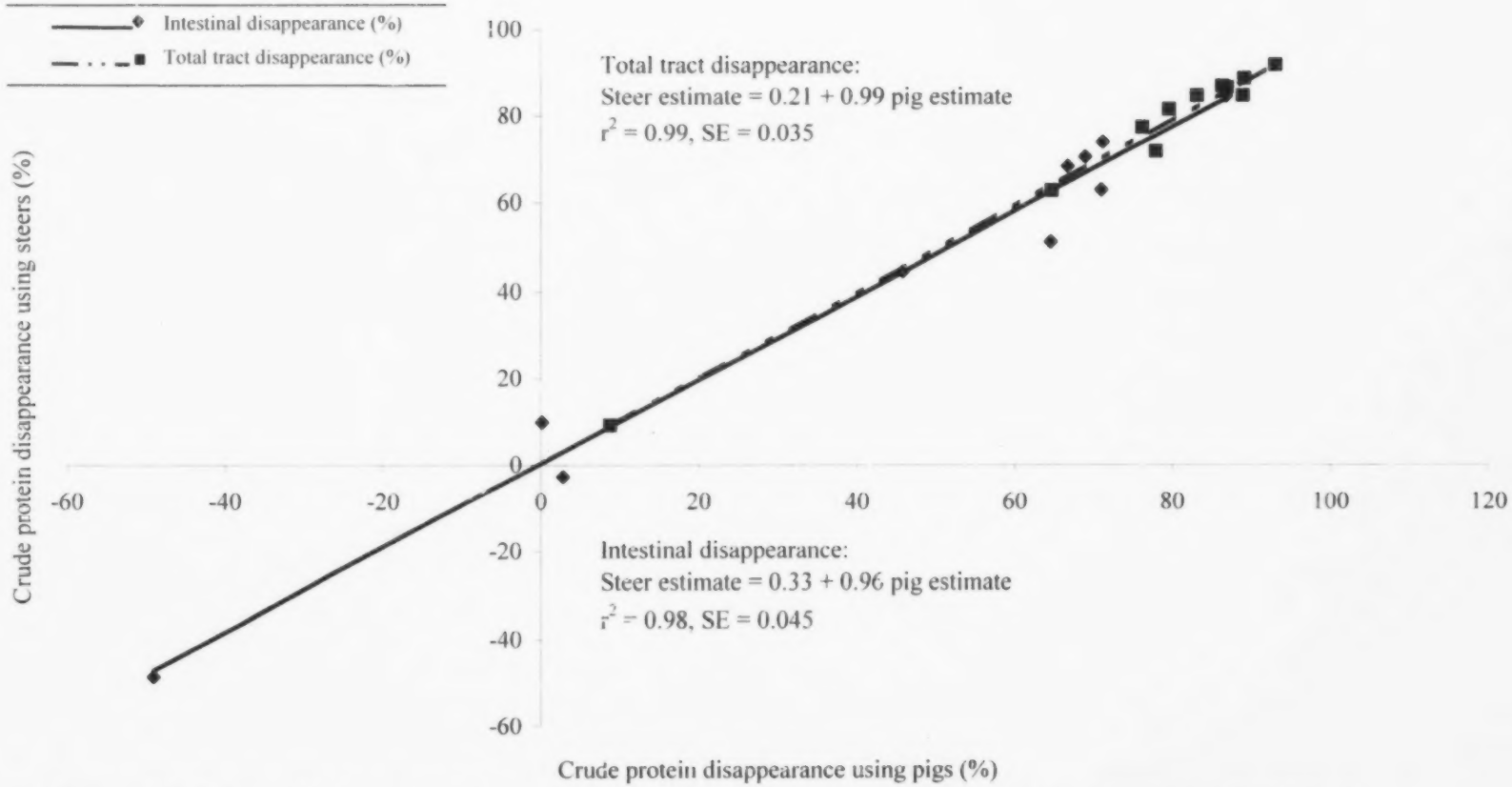

Figure 2.3. Relationship (non-zero intercept) between relating pigs and steers for measuring intestinal and total tract disappearance of rumen undegraded protein of various protein supplements and forages. Each point represents the mean of 16 bags of feed sample.

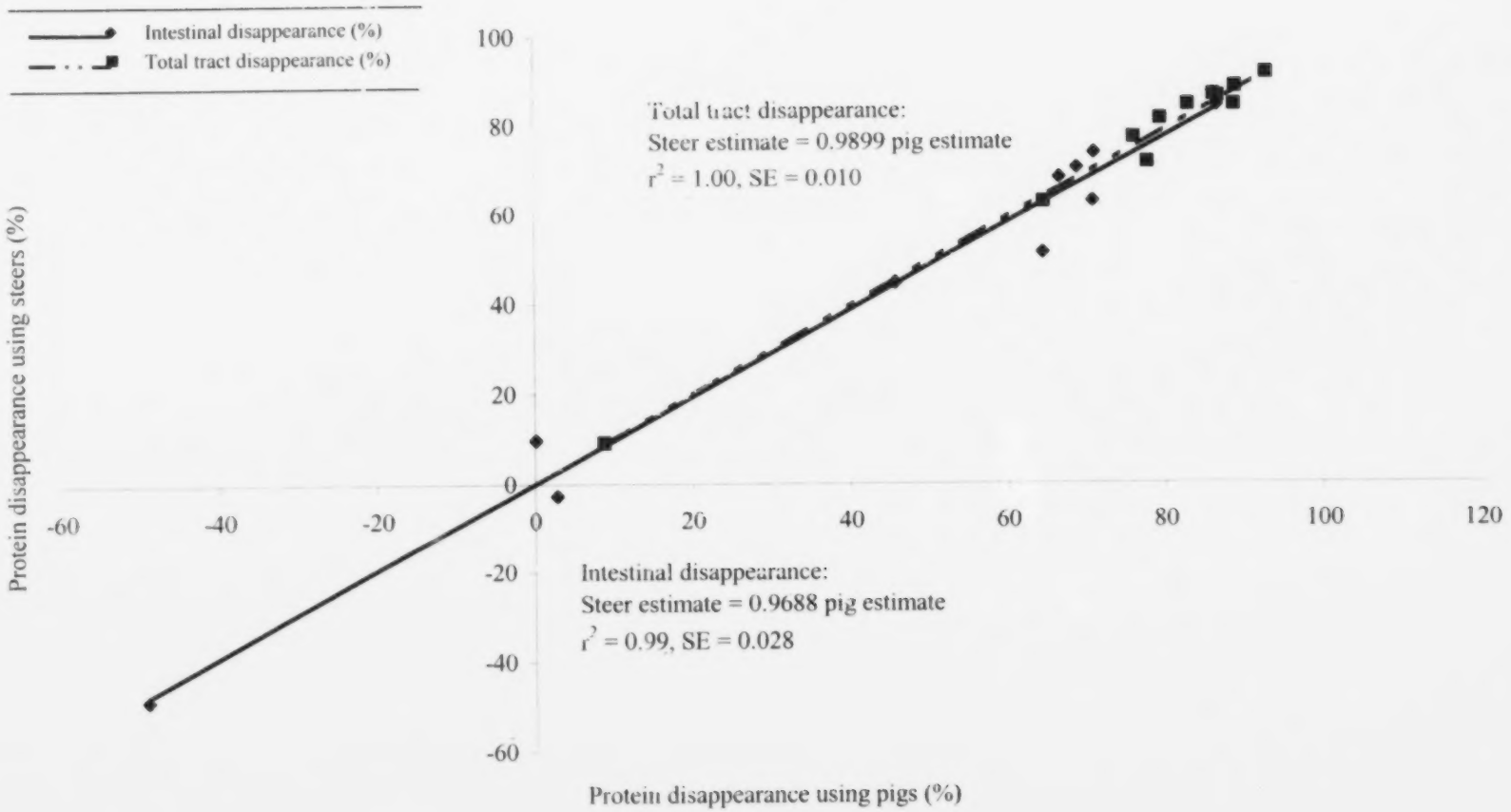

Figure 2.4. Relationship (zero-intercept) between pigs and steers for mesuring intestinal and total tract disappearance of rumen undegraded protein of various protein supplements and forages. Each point represents the mean of 16 bags of feed sample.